An Ultrasonic Beam Actograph for Laboratory and Field Use

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ABSTRACT

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Described is a system for automatically recording locomotor activity of animals in lab and field situations. In principle, the interruption of ultrasonic beams (operating at 200 kHz and pulsed at 25 Hz) by moving animals is used as a measure of their activity. Power is supplied by two common 12 V car batteries. The frequency of beam-interrupt events is recorded on a modified hand-held type printing calculator, via specific signal accumulating and timing circuits described here.

Key words: locomotor activity, circadian rhythms, ultrasound, environmental pollution, sublethal effects, monitoring.

RESUME

Scherer, E. and B. van der Veen. 1982. An ultrasonic beam actograph for laboratory and field use. Can. Tech. Rep. Fish. Aquat. Sci. 1137: iv + 15 p.

Voici la description d'un dispositif servant à relever automatiquement les mouvements locomoteurs des animaux en laboratoire et dans leur milieu naturel. Comme les ondes ultrasoniques de l'appareil (fréquence de 200 kHz avec impulsions à 25 Hz) s'interrompent sous le moindre mouvement des animaux, on se sert de cette caractéristique de l'appareil pour mesurer les mouvements de ces derniers. Le dispositif est alimenté par deux accumulateurs ordinaires de voiture de 12 volts. La fréquence des interruptions est notée sur une calculatrice imprimante compacte, par l'entremise de circuits accumulateurs et temporiseurs conçus pour les signaux et décrits ci-dessous.

Mots-clés: mouvements locomoteurs, rythmes circadiens, ultrason, pollution environnementale, effets sublétaux, surveillance continue.

INTRODUCTION

Locomotor activity in relation to natural environmental factors such as light, temperature, barometric pressure, etc. and their spatial and temporal variations is of basic interest to biologists (e.g. Fry 1947; Brown et al. 1970; Thorpe 1978). The causal analysis of activity levels and patterns usually requires laboratory experiments under well-controlled conditions. Determining the natural shape and variability of such patterns and their biological significance (e.g. in regard to feeding, migration, spawning) usually depends on field investigations.

A further need was added by attempts to assess man-caused perturbations of environmental conditions and resulting biological effects. Monitoring of animal locomotor activity has been suggested as a tool to detect sublethal contaminant effects in laboratory tests or on-site (e.g. Waller and Cairns 1972; Scherer 1977, 1979, Morgan 1979).

In either case, accurate and reliable activity recording is needed. We looked for and did not find a method that would be equally suitable for laboratory and field investigations of aquatic organisms, especially fish. A classic technique employs visible or (preferably) invisible light beams, whose automatically recorded interruptions by moving animals provide a measure of their activity. Light, however, is readily scattered and absorbed in water, particularly in the invisible UV and IR range and in contaminated waters with any significant concentrations of organics or suspended matter (Sauberer and Ruttner 1941; Hutchinson 1957). Ultrasound, by comparison, penetrates water very well (Bhatia 1967; Albers 1972), at frequencies well above the hearing range of fishes and most aquatic organisms (Popper and Fay 1973). Moreover, over the past 10-20 years ultrasonic transducers of various specifications (frequencies, energy outputs, extent of collimation) have become commercially available at moderate prices, as have printed circuit techniques and printing calculators with low power requirements.

Therefore, a project to develop a battery-operated, compact and easily portable recording system based on ultrasonic beam interruption was initiated at the Freshwater Institute a few years ago. After several design changes and improvements, we arrived at a very satisfactory prototype, described in this report.

DESIGN DESCRIPTION

The ultrasonic motion detector and data collection system (Fig. 1) consists of three major component packages whose function and operation will be explained as follows.

The first package is the power supply. The second contains the elements for the ultrasonic beams: the timing circuit, transmit/receive circuit, sample/hold comparator, and the signal interface. The third package contains the clock, clock and data interface, and the printing calculator. Our description basically follows the signal path through these three "packages".

The operating frequency of the ultrasonic beams is 200 kHz, with a repetition rate of 25 Hz. Each beam consists of a transmit and a receive transducer, operating in a pulsed mode, and the circuitry ensures that each receive transducer only receives the signal of its appertaining transmitter. The six ultrasonic beams in our prototype unit were considered suitable for most of our applications, but this number could be modified without difficulty.

Power supply (Fig. 2)

Power is supplied by two lead acid car batteries connected back-to-back with a common negative. Battery #1 supplies power to the voltage regulator LM305 for the 5 V logic supply, and 12 volts to the transmit/receive and signal processing circuits. Battery #2 supplies the power to the 6 V regulator 7806 to charge the battery pack in the calculator, and to a diode to provide 11.5 V to be used by the calculator and clock circuit. The calculator provides 18 V for interfacing calculator, clock and data output.

One set of fully charged batteries will insure operation for 1 to 2 weeks.

Ultrasonic beams (Fig. 3, 4, 5)

The transmit drive pulse is generated by integrated circuit IC1 in the timing circuit (Fig. 3). The frequency is 25 Hz, adjustable by a 10 kΩ potentiometer. The following integrated circuit IC2 changes the pulse width from 20 ms to 25 µs, again adjustable by a 10 kΩ potentiometer. The transistor provides the current to drive the 6 transmitters. The 25 µs pulse from the timing circuit performs three functions:

1. turns on the transmitter;
2. turns on integrated circuits 5 and 6 (see Fig. 4) to determine the time period during which the "receive" window is open,
3. sets the refresh lines high and discharges the sample/hold capacitor C7 (Fig. 5).

As Fig. 4 illustrates, the pulse coming from the timing circuit at a rate of 25 Hz and a pulse width of 25 µs is amplified by Q3 and triggers the LM1812N ultrasonic transceiver in the transmit mode for 1 µs with a frequency of 200 kHz determined by L2 and C4. The autotransformer L1 output voltage is about 150 volts peak to peak and the pulse width is about 10 µs. This signal goes to the transmit transducer. If there is no obstruction in the beam path, the signal is detected by the receive transducer, amplified and processed in the LM1812N, and further amplified by the LM2902 amplifier. The "receive" window ensures that the LM1812N processes only the signal from its corresponding transmit beam. This window is set to be open at the calculated time, i.e. when the receive signal is expected at the LM1812N. Adjustments are made by R14 and R11.

Before the signal enters the sample/hold circuit (Fig. 5), a refresh signal discharges

the sample/hold capacitors through tramsistor Q4, i.e. capacitor C7 is set to near zero voltage. When the signal arrives from ID2, it charges capacitor C7 to a value determined by the receive transducer. This signal is amplified and directed to the comparator CA3098 and to the 50 μA meter. The comparator only produces an output if the signal has a level that falls between the high and low voltages set by R3 and R4. Note that by switching to either positions 3 or 4, and using the 50 μA meter, the high and low limit input voltage level to the comparator can be set.

The output of the comparator is further processed by two NAND gates and IC3. The diode D5 between the output of the comparator and the input to IC3 acts as a steering diode to prevent interaction between the six comparators. The negative output pulse produced by IC3 is fed into the clock and data interface circuitry (Fig. 8).

Clock and data interface (Fig. 6 to 10)

The clock provides a visual time-of-day display, and also feeds into the calculator printout. The time-of-day decoding in hours and minutes is done by IC's 24, 23, 22 and 20. IC25 and IC23 receive the same input signal. IC25 selects the sampling time interval, in our prototype set at 60 minutes (i.e. hourly printout of time-of-day and beam-interrupt counts accumulated over the preceding 60 minutes). The time is decoded again by IC11 (Fig. 7) and directed on to the printer keyboard, which is hardwired into the clock-data interface.

IC17 (Fig. 8) determines the sequence in which time and data are entered into and printed out by the calculator. The sequence is as follows:

1. enter the time, Q1, Q2, Q4 and Q5 from IC17,
2. print command (#), Q6 from IC17;
3. print data (T), Q7 from IC17;
4. enter 1, Q8 from IC17;
5. print command (#), Q9 from IC17.

The data and control signals are further processed in the voltage amplifier by the 16 comparators IC2, 9, 15 and 21 together with 15 analog switches IC1, 3, 4 and 5. As mentioned before, the analog switches are hardwired directly into the keyboard of the printing calculator. Note: the clock signal enters the printing calculator through the individual digit on the keyboard, but the count input enters data through the "+" key of the calculator. Since the 4th instruction to the calculator is "enter 1"(one), and instruction no. 5 is print command, for each count pulse a "1 +" will be printed if the actograph is in the manual mode. This allows the experimenter to observe activity events as they happen and to obtain an interim sum of counts at any time. In the auto mode, the printer is partially disabled. The data count is accumulated in the calculator and only printed out upon instruction no. 3, "print data T" (total) and only the total count for a preset time interval (e.g. every hour) is printed.

The function of the operating controls are as follows:

"On/off" switches power to calculator, clock display and logic board. When the power switch is in the "off" position there is no time display, but the clock continues to keep time, power is supplied for that purpose by a small 9 V battery. The "hours set" and "minutes set" controls in combination with a display command switch allow to set the correct time of day.

The mode switch "auto" and "manual" operates as follows:

In the "auto" mode: prints only after timing interval or whenever the "manual record" switch is pressed. The printing format is: time-of-day, e.g. 1200# - read as 12 hours, 00 minutes. Count in, e.g. 23T - read as 23 activity counts in time interval.

In the "manual" mode: prints immediately after each beam interruption event occurs (i.e. 1+, 1+, 1+, 1+, etc.) after the timing interval, or whenever the "manual record" switch is pressed in the "manual" mode. The printing format is: time-of-day, e.g. 1234# - read as 12 hours, 34 minutes. Count in, e.g. 48T - read as 48 activity counts in time interval. Enter 1# - command to start counting.

DISCUSSION

As indicated in the INTRODUCTION, the present design came about after a number of both minor and major modifications.

An idea pursued initially was to utilize the principle of a diffuse ultrasonic standing wave pattern and its disruption by moving objects (as in certain commercially available burglar alarm systems). The attractive feature would have been a quite homogeneous "illumination" with equal sensitivity throughout a certain tank or a field area. However, experiments with a prototype ended in failure: in practice, the system was found to be inherently and incurably unstable. Its sensitivity changed significantly in relation to normal, unavoidable build-up and fluctuations of absorptive organic materials in the water and on the bottom or the tank walls (food, feces, algae, etc., Nowak and Freese, unpubl. data). The present beam approach, while safely insensitive to such interferences, certainly shares one apparent shortcoming with any other method using beams (such as of light): there are "dead", i.e. insensitive areas between beams. However, we found this fact acceptable. The experimenter usually requires a relative (but stable) rather than an "absolute" measure of activity (which may be hard to define, regardless of the recording method used). Number and positioning of beams in the experimental area can be easily varied in preparatory pre-test trials with checks for possible effects on the recorded activity pattern. We see a distinct advantage of the present method in its applicability to both laboratory and field investigations, allowing for better comparability of data.

Our own experience is so far restricted to work with fish (e.g. Fig. 12). It appears fea-

sible to extend the application of this method to invertebrates and terrestrial species.

Total costs of parts and supplies amount to approximately Can. $2000.00, as the following list shows:

2	batteries $60.00 ea.	$ 120.00
12	transducers $50.00 ea	600.00
8	printed circuit boards	360.00
1	digital clock	35.00
1	printing calculator	100.00
70	integrated circuits $3.00 ea.	210.00
70	IC sockets $2.00 ea.	140.00
47	transistors $1.00 ea.	47.00
4	switches $5.00 ea.	20.00
6	meter movements $20.00 ea.	120.00
	chassis	40.00
	cables and connectors	200.00
		$1992.00

ACKNOWLEDGMENTS

We gratefully acknowledge the help we received from Messrs. S. E. Nowak and D. L. Kripiakevich who contributed to design and assembly of the prototype, Messrs. H. J. Ballon and K. R. Scott reviewed and improved the manuscript; figures were prepared by Mr. L. Taite; typing and word processing by Mrs. D. Laroque and Mrs. L. Fletcher; editorial corrections by Mrs. M. Layton.

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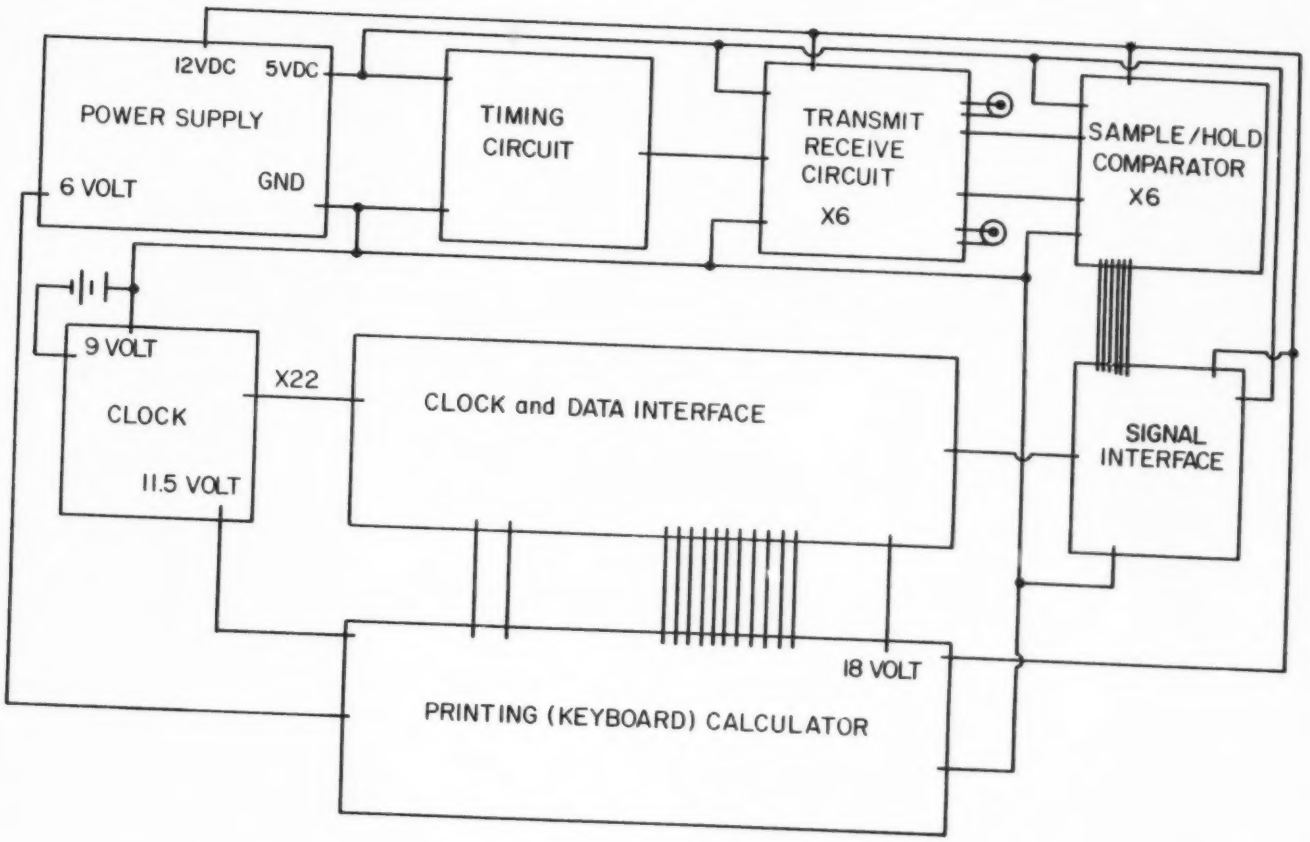

Fig. 1. Block diagram. Major functional components of the ultra-sonic beam actograph.

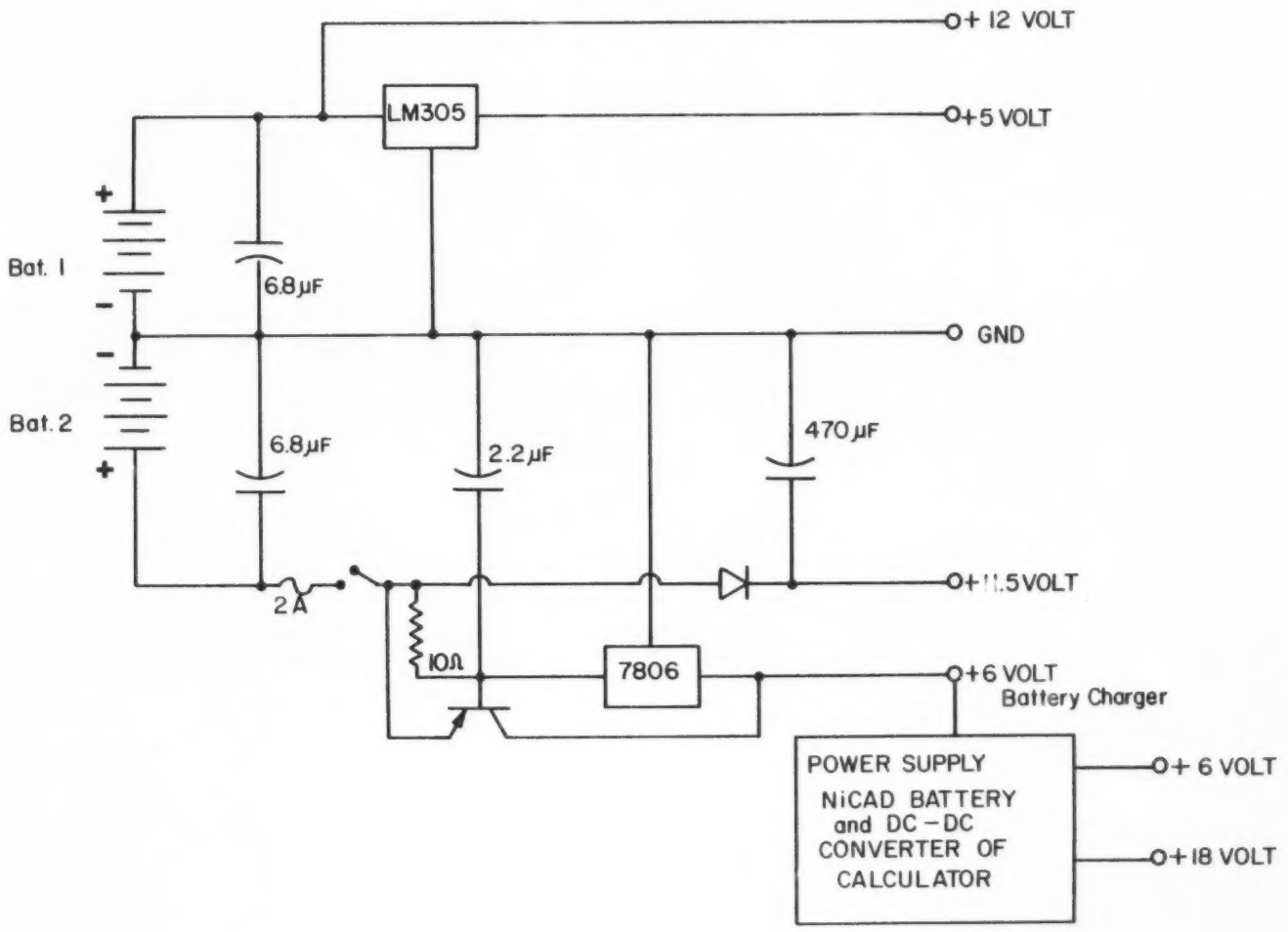

Fig. 2. Power supply.

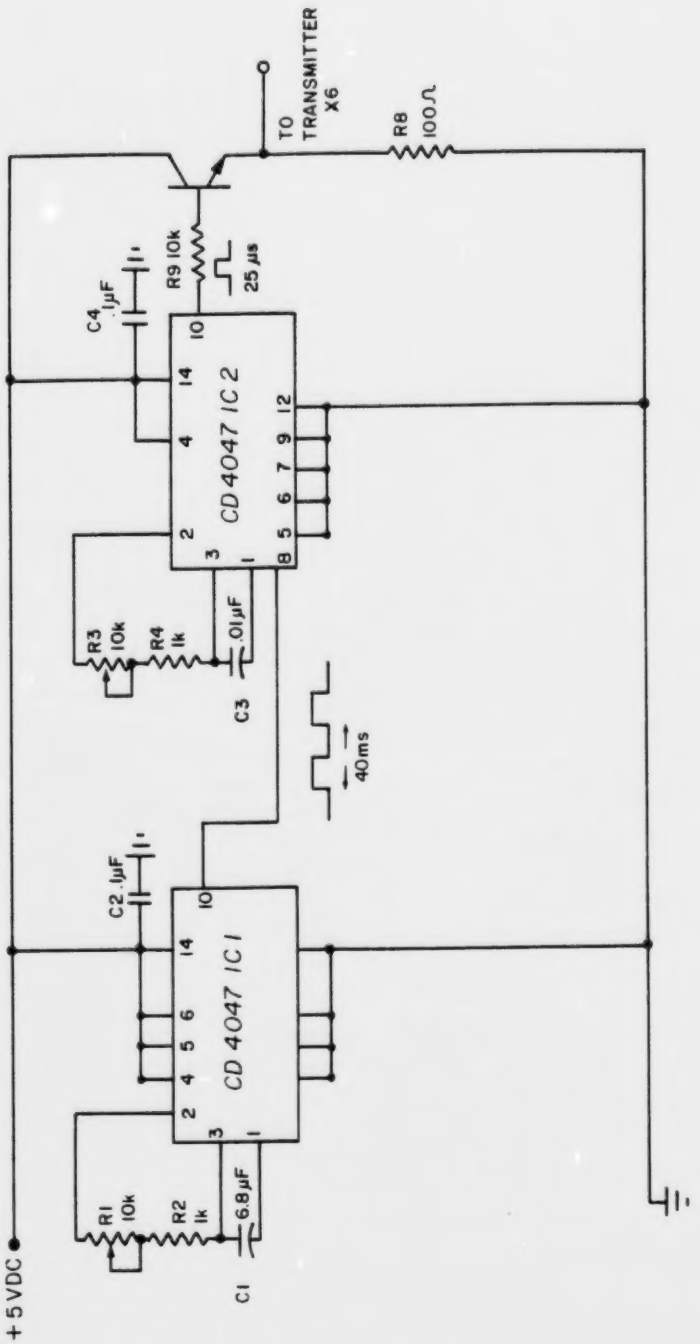

Fig. 3. Timing circuit.

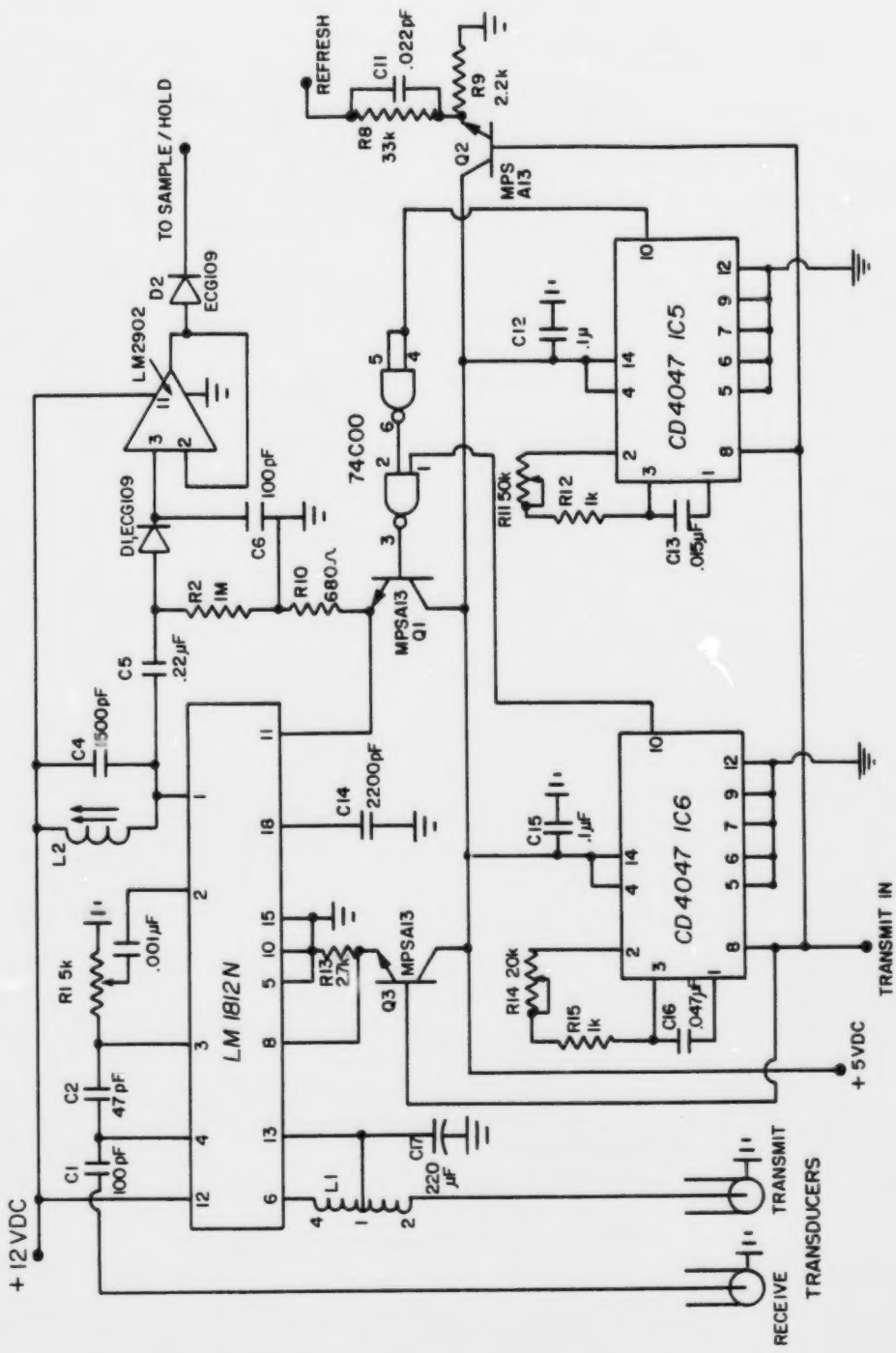

Fig. 4. Transmit/receive circuit.

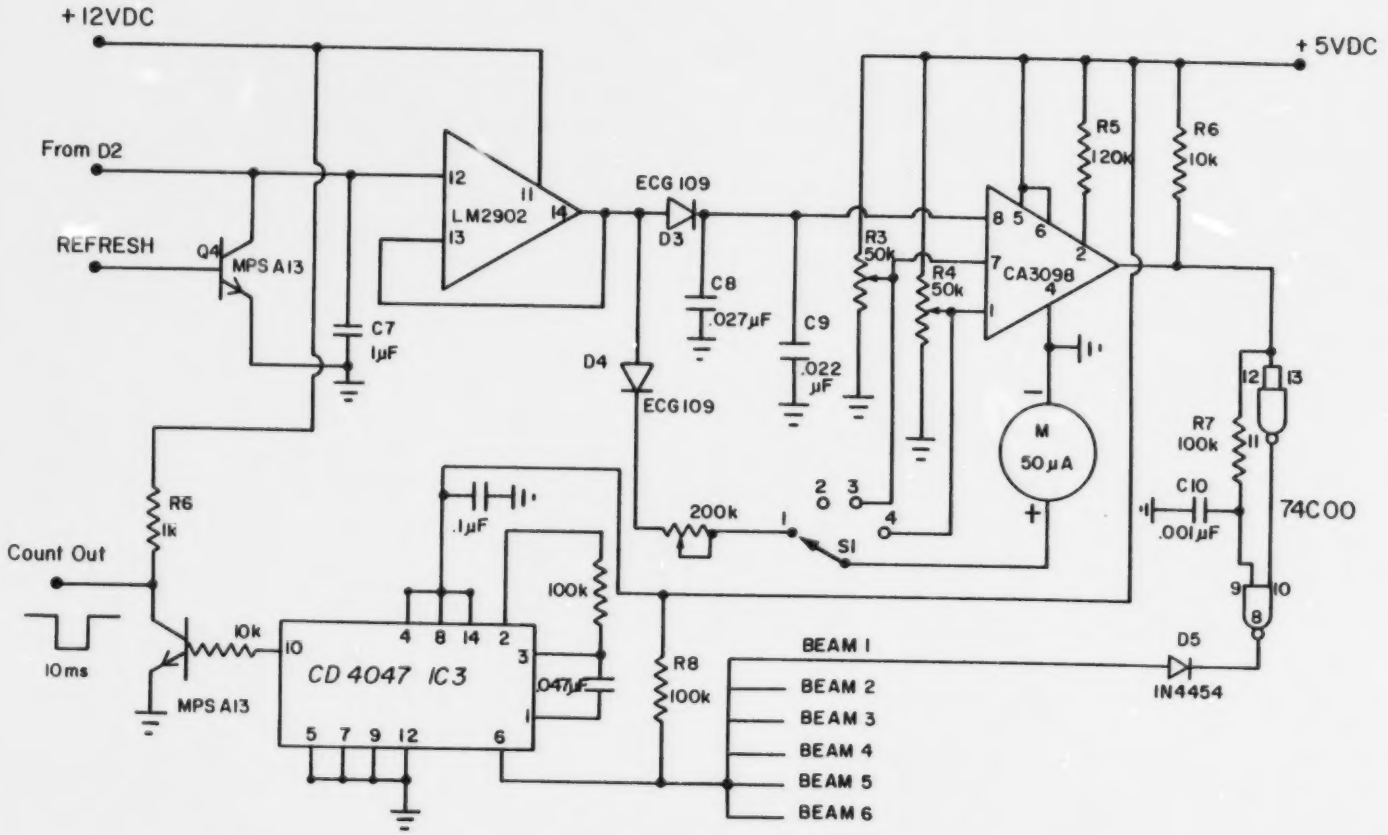

Fig. 5. Sample/hold, comparator and interface.

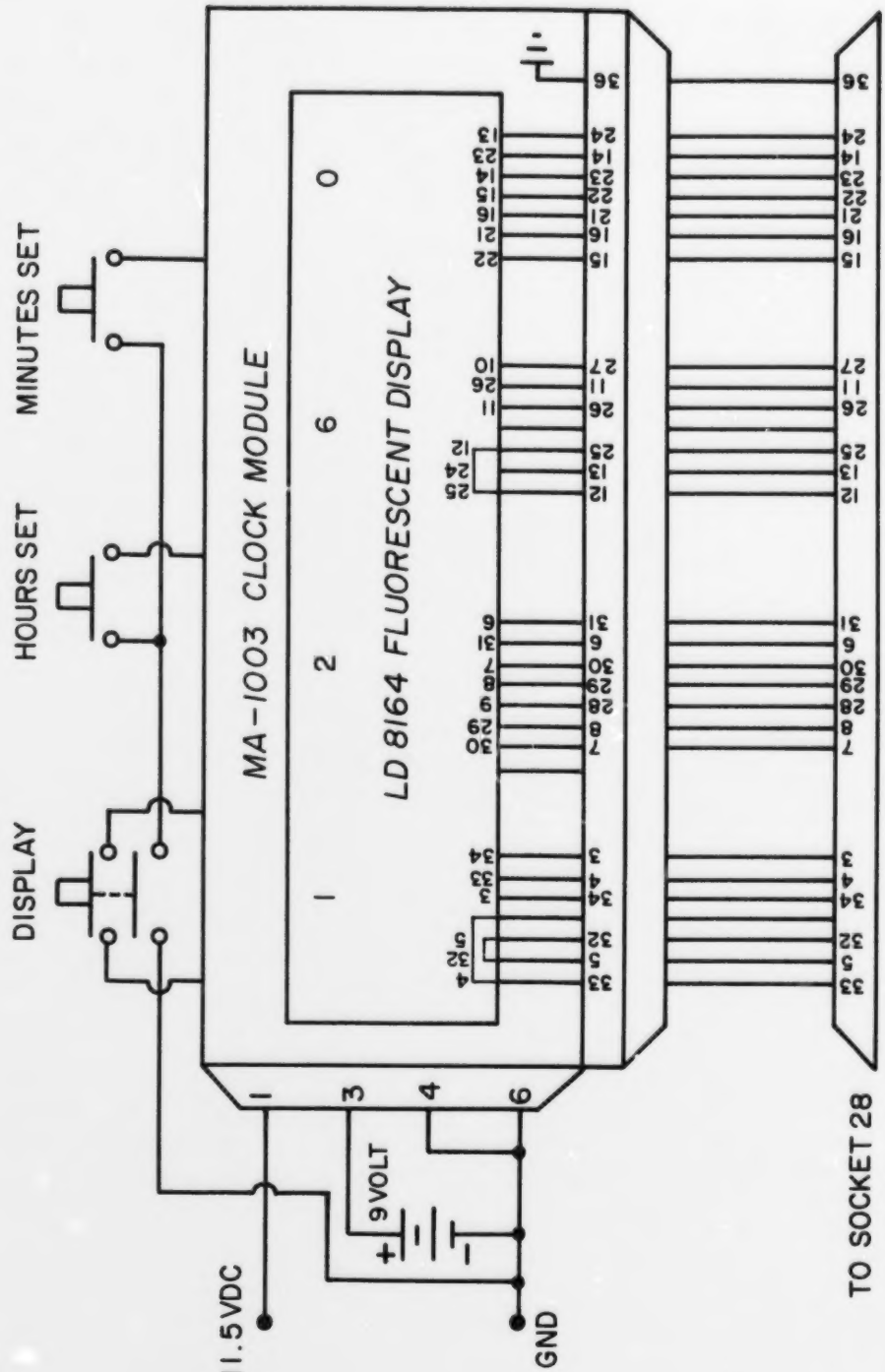

Fig. 6. Clock diagram.

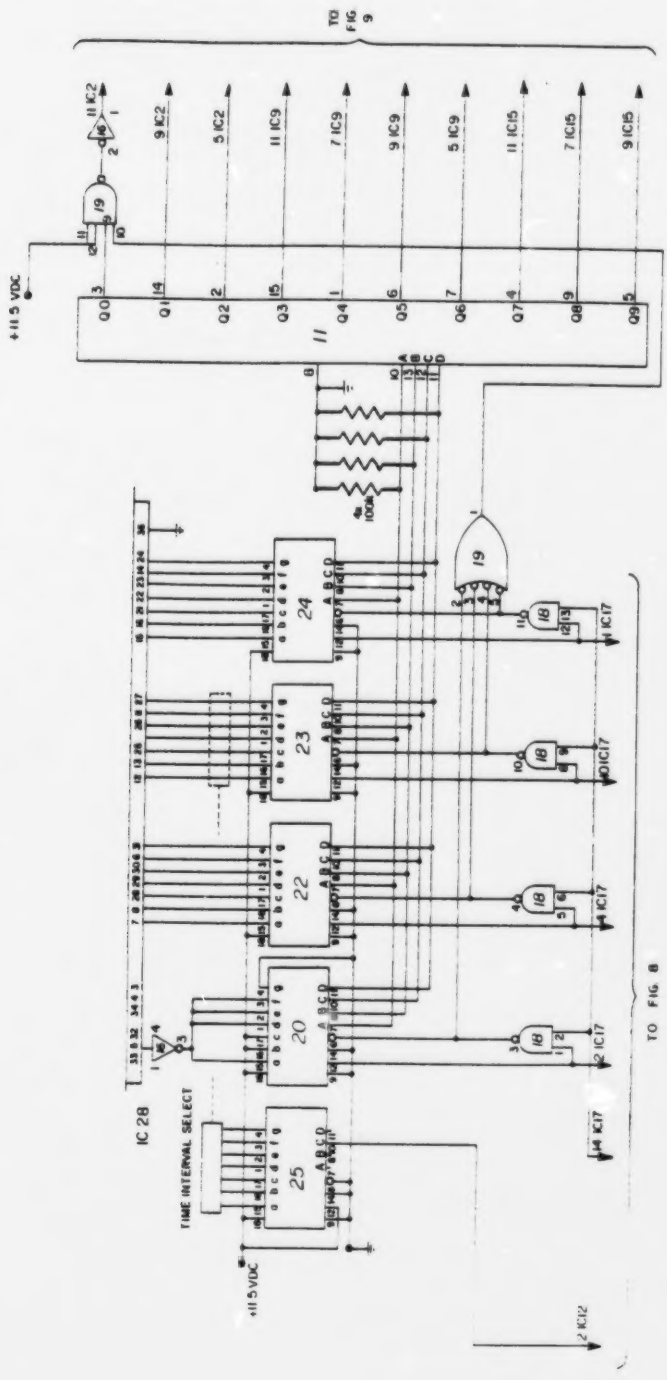

Fig. 7. Clock and data interface circuit I.

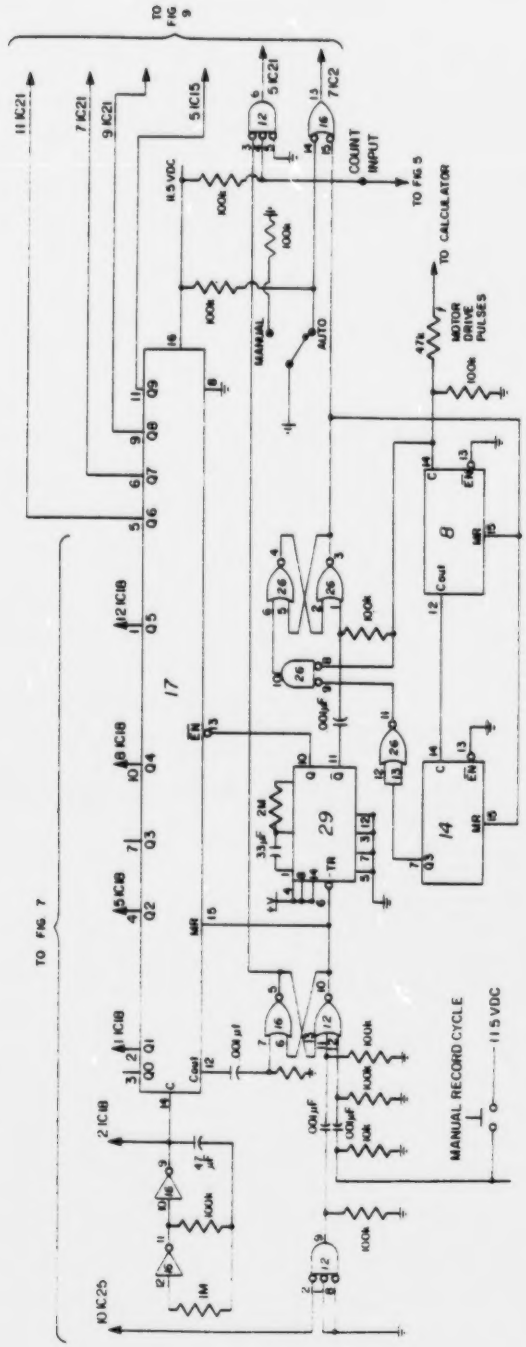

Fig. 8. Clock and data interface circuit II.

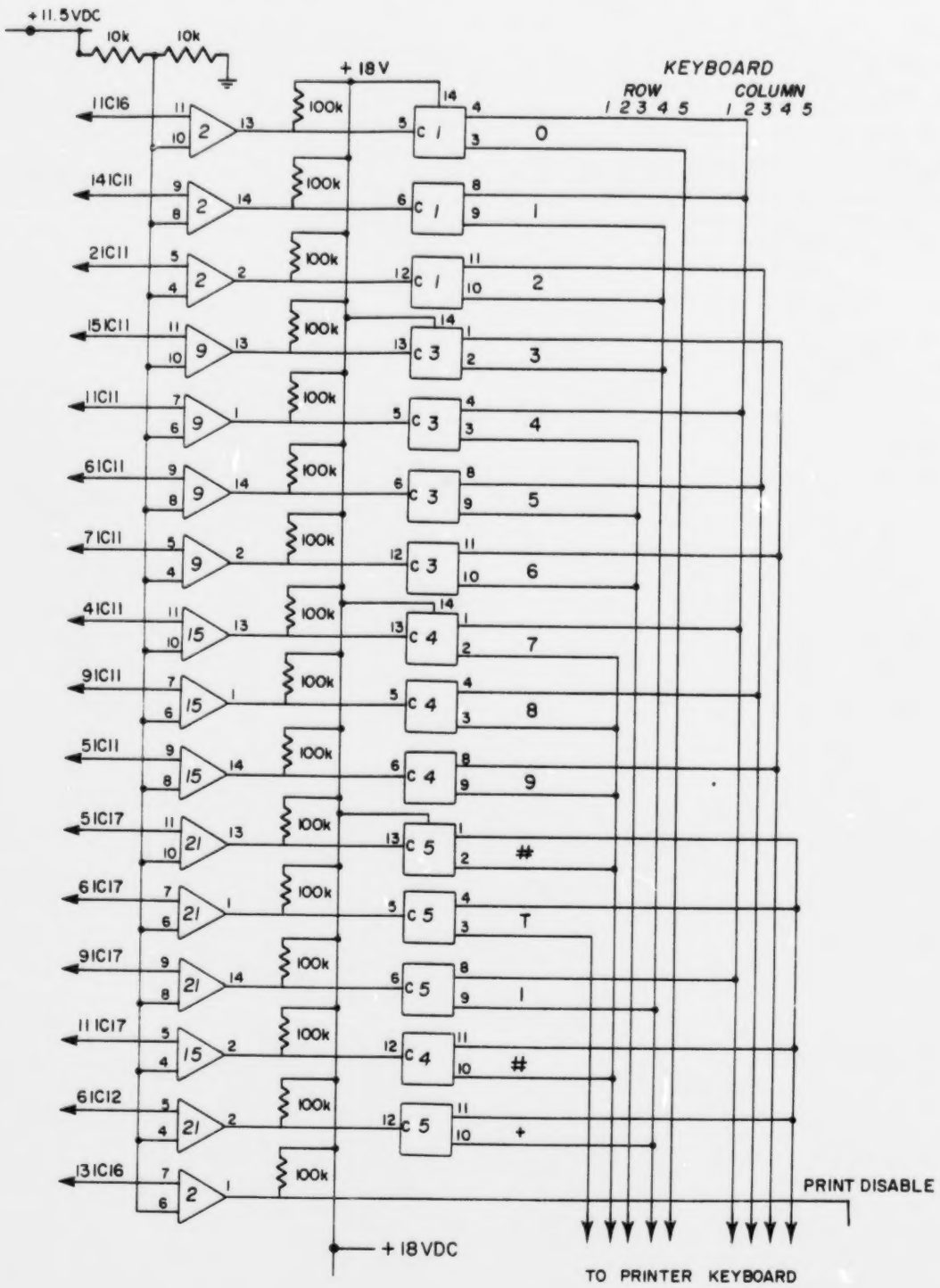

Fig. 9. Clock and data interface circuit III.

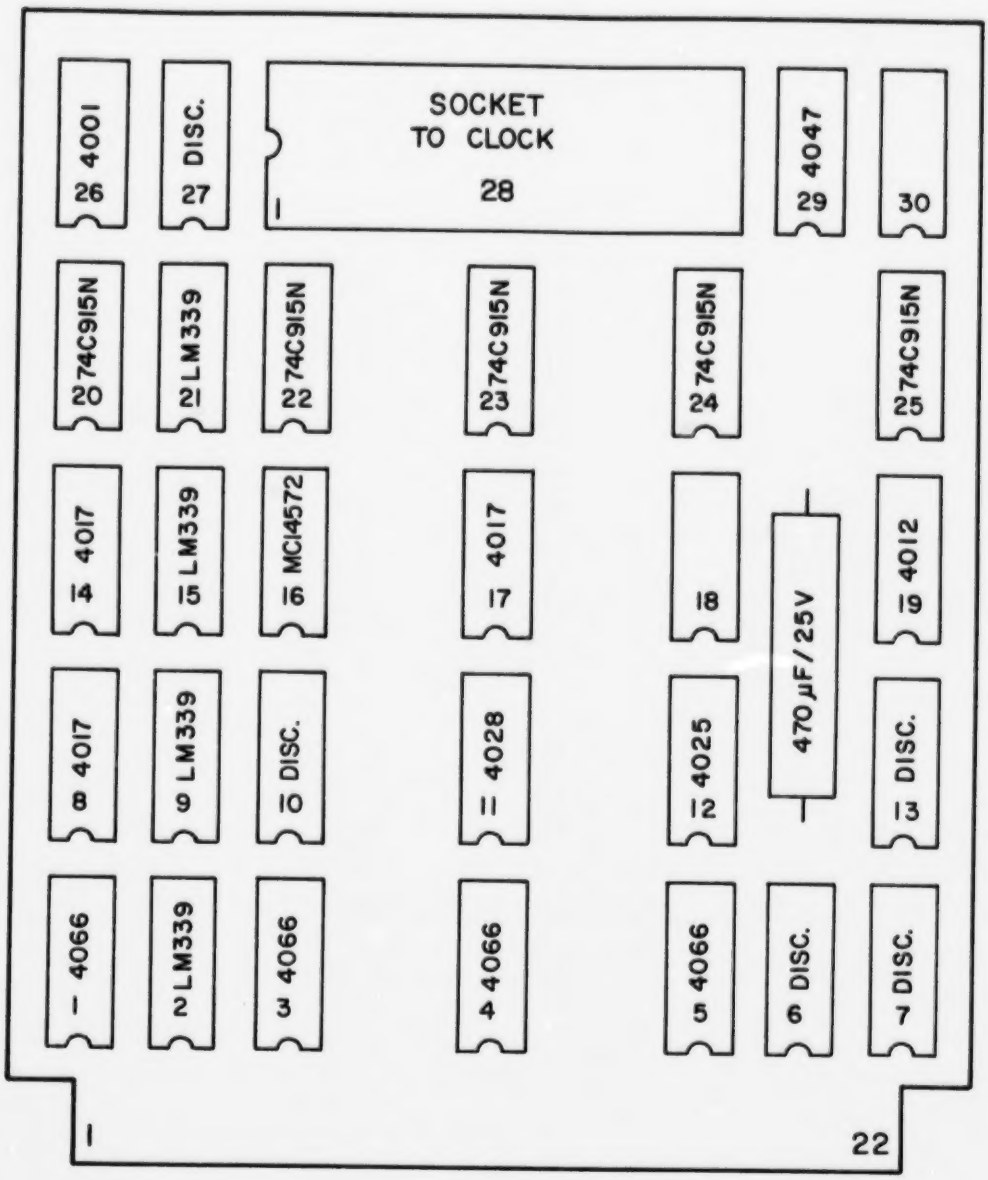

Fig. 10. Circuit board layout of clock and data interface.

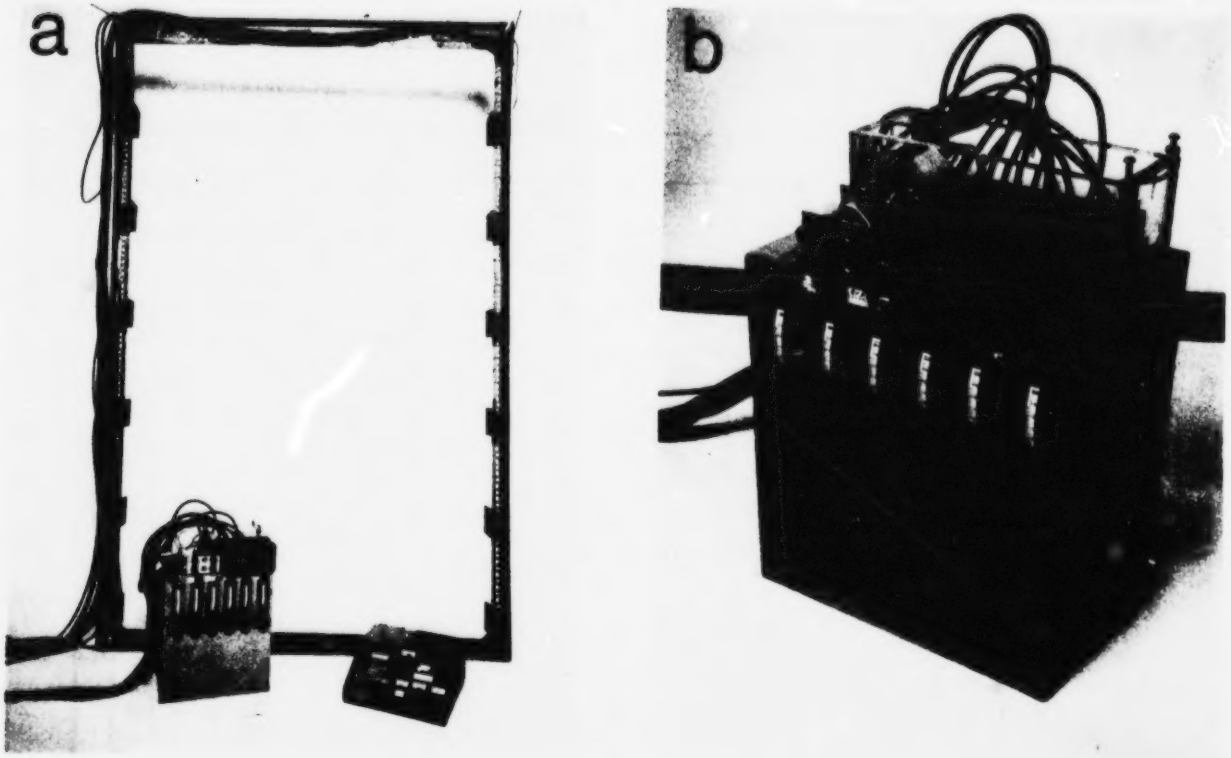

Fig. 11. Completely assembled system.

a: 6 transducer pairs mounted on a support frame, and 2 modules containing electronics

b: module for timing, transmit/receive, sample/hold, comparator and signal interface

c: module containing clock/data interface and printing calculator.

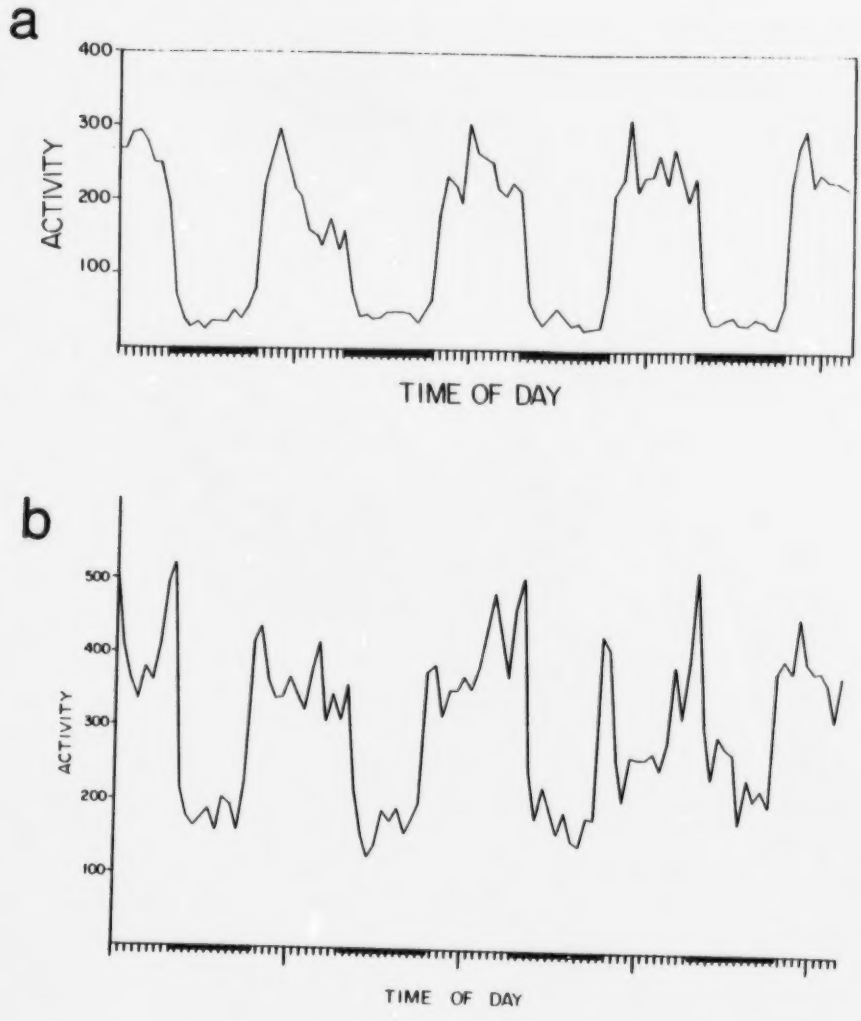

Fig. 12. Examples of fish activity recordings.

Activity counts (= beam interrupt events) on y-axis; abscissa with hourly divisions; 12:00 noon indicated by an extended line; black horizontal bar denotes night (lights off) phase.

a: Laboratory recording of lake whitefish (Coregonus clupeaformis) activity. Twenty-five fish in a circular pool (5 m diameter, 1 m deep); 2 banks of 3 vertically stacked beams transecting the pool; temperature 21.5°C; photoperiod 12 L:12 D; 2900 lux at midwater depth; feeding daily at 11:00 a.m.

b: Field recording of lake whitefish (Coregonus clupeaformis) activity. Ten fish in a 1.2 x 1.2 x 1.8 m cage suspended in lake. Six beams arranged at equal intervals from top to bottom of the cage. Temperature 15 - 18°C; photoperiod 12 L:12 D; maximum light intensity at bottom of cage 7200 lux; no feeding.

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